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Reactions induced by ^{11}Be beam at Rex-Isolde

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Abstract. The collision induced by the three Beryllium isotopes, ^{9,10,11}Be, on a ^{64}Zn target were investigated at $E_{c.m.} \approx 1.4$ the Coulomb barrier. The experiments with the radioactive ^{10,11}Be beams were performed at the Rex-Isolde facility at CERN. In the case of ^{9,10}Be, elastic scattering angular distributions were measured whereas, in the ^{11}Be case, the quasielastic scattering angular distribution was obtained. A strong damping of the quasielastic cross-section was observed in the ^{11}Be case, in the angular range around the Coulomb-nuclear interference peak. In this latter case a large total-reaction cross-section is found. Such a cross-section is more than a factor of two larger than the ones extracted in the reactions induced by the non-halo Beryllium isotopes. A large contribution to the total-reaction cross-section in the ^{11}Be case could be attributed to transfer and/or break-up events.

1 Introduction

Elastic scattering, being a peripheral process, allows one to investigate the surface properties of the halo nuclei. In this contribution we investigate to what extent information can be obtained from elastic scattering measurements of high quality, at low bombarding energies. Low energy elastic scattering and reaction experiments, involving halo nuclei, have been performed mostly with ^{6}He, which is a 2n-halo nucleus, on several targets over a wide range of energies and masses. The studies performed at low bombarding energy have shown that coupling to the continuum strongly affects the elastic cross-section especially on heavy targets and that direct processes are favored over, for example, fusion. On heavy targets, coupling with the Coulomb dipole excitation of the low-lying E1 strength, produces a suppression of the elastic cross-section at forward angles, in the Coulomb-nuclear interference region [1]. This suppression has not been observed in reactions induced on low charge targets as for example ^{64}Zn [2]. On this target, however, the elastic cross-section is overall suppressed when compared to the elastic cross-section of the well bound ^{4}He nucleus at the same $E_{c.m.}$ on the same ^{64}Zn target [2]. In the ^{6}He induced reactions the total-reaction cross-section is large (see e.g. [2,3]) and at low energies, as above mentioned, direct processes such as transfer and break-up are the ones that mostly contribute to this cross-section.

In the reaction induced by the 1n-halo ^{11}Be nucleus on a ^{209}Bi target, at energies that exceed 10% the Coulomb barrier, the extracted total-reaction cross-section was found to be similar to the one of ^{9}Be+^{209}Bi [4,5], measured by the same group [6].

In this contribution results of experiments performed with the three Beryllium isotopes ^{9,110,11}Be on a medium mass ^{64}Zn target will be discussed.

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2 Experiments

Two separate experiments were performed in order to study the three reactions ^{9,10,11}Be+^{64}Zn. The experiment with the stable ^{9}Be beam was done at Laboratori Nazionali del Sud (LNS) in Catania. The ^{9}Be beam was delivered by the 14MV Tandem accelerator of LNS and it was impinging on a 550 μg/cm^{2} 99% enriched ^{64}Zn target at a center of mass energy of 24.9 MeV. The elastic-scattering angular distribution was measured using five collimated surface barrier Si detector telescopes (10 μm ΔE and 200 μm E detectors), placed on a rotating platform, in the angular range $10^{0} \leq \theta_{\mathrm{c.m.}} \leq 110^{0}$.
The experiment with the radioactive beams was performed at Rex-ISOLDE (CERN). The radioactive ^{10}Be and ^{11}Be beams are produced using spallation reactions induced by 1GeV p beams impinging on a thick Ta target. The 1^{+} ionized Beryllium atoms are extracted from the Ta target, purified in the High Resolution Separator and after charge breading, performed with the Electron Beam Ion Source (EBIS), are post-accelerated in the Rex-Isolde linear accelerator and sent to the target for the experiment. The average beam intensity was 10^{6}pps for ^{10}Be and 10^{4} pps for ^{11}Be with a purity of better than 99%.
In the ^{10,11}Be+^{64}Zn experiment the beam energy was $\mathrm{E_{c.m.}} \approx 24.5$ MeV and the target was a 550 μg/cm^{2} and a 1000 μg/cm^{2} for the ^{10}Be and ^{11}Be beams respectively. The detector system used was an array of six Si-detector-telescopes each formed by a 40 μm, 50 × 50 mm^{2}, ΔE DSSSD detector (16+16 strips) and a 1500 μm single pad E detector. This array was placed very close to the target; this allowed a large solid angle coverage. The angular range covered by the detector was $10^{0} \leq \theta_{\mathrm{lab}} \leq 150^{0}$. However due to the limited statistics, only data up to $\theta_{\mathrm{c.m.}} \approx 100^{0}$ were analised. More details on the experiment can be found in [7].
In the ^{11}Be case, due to the energy resolution of the radioactive beam and the energy straggling in the target, it was not possible to separate the ground state from the bound $\frac{1}{2}^{-}$ (E_{x}=0.32MeV) state in ^{11}Be. As a consequence, in the ^{11}Be case, the quasielastic scattering rather than the elastic scattering was measured.

3 Results and discussion

3.1 Elastic scattering angular distributions

In Fig. 1 the elastic scattering angular distribution for ^{9,10}Be+^{64}Zn and the quasielastic scattering angular distribution for ^{11}Be+^{64}Zn are shown. As one can see from the figure, the angular distributions for ^{9,10}Be+^{64}Zn appear to be very similar. This result is not surprising. It is known in fact [8], that although ^{9}Be is a weakly bound nucleus, at energies above the Coulomb barrier the break-up channel does not give an important contribution to the total reaction cross-section. In the ^{9}Be+^{64}Zn collision measured in [8] the reaction channel that mostly contribute to the total reaction cross-section is the total-fusion. This result is similar to what expected in reactions induced by well bound nuclei such as ^{10}Be. On the other hand, the ^{11}Be+^{64}Zn quasielastic angular distribution shows a very different behaviour; the peak due to the interference between the Coulomb and nuclear amplitude is missing and the quasielastic cross-section appears to be suppressed at the angles at which the nuclear interaction is felt. The observed feature, which cannot be attributed to the strong coupling to the bound 1^{st} excited state of ^{11}Be since this channel is included in the quasielastic cross-section, is typical of absorption occurring at large distances. Similar features have been observed when a strong coupling with the Coulomb excitation of quadrupole states in heavy deformed nuclei is present due to a long-range interaction such as the Coulomb interaction [9].

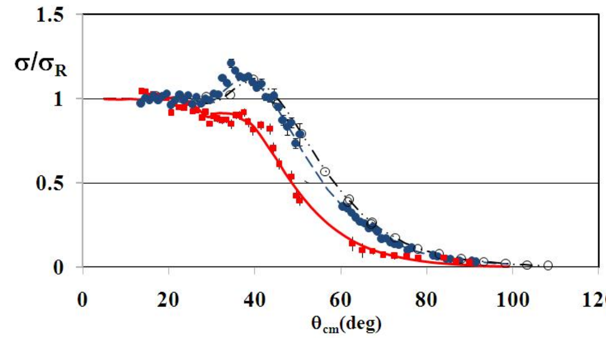

Fig. 1. Elastic scattering angular distribution for ^{9}Be+^{64}Zn open symbols and ^{10}Be+^{64}Zn, blue symbols. Quasielastic angular distribution for ^{11}Be+^{64}Zn, red symbols. Lines represent the result of the Optical Model fit to the data (see text for details).

In the ^{11}Be case, absorption at large distances may occur due to the large radial extension of the halo nucleus. As shown in [10], the suppression of the elastic cross-section in the Coulomb-nuclear interference region cannot be attributed to Coulomb dipole coupling even though there is the presence of a low-lying E1 strength near the threshold but this suppression is mainly due to the nuclear contribution. In [10] one can see that the Coulomb-nuclear interference contribute further to the suppression of the elastic cross-section in the so called "rainbow" region. A strong coupling to the Coulomb dipole strength is instead expected to be important in the scattering with heavy targets having high Z [11], as indeed observed in collisions induced by the 2n-halo ^{6}He nucleus see e.g. [1].

3.2 Optical Model analysis.

The ^{9,10,11}Be+^{64}Zn scattering angular distributions were analyzed within the Optical Model (OM) framework using the code PTOLEMY [12]. For the ^{9}Be+^{64}Zn

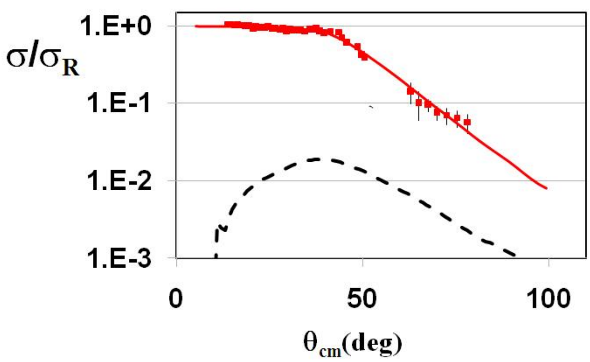

Fig. 2. Quasielastic angular distribution for ^{11}Be+^{64}Zn, red symbols. Full red line represent the result of the Optical Model fit to the data. Dashed black line represent DWBA calculations of inelastic scattering.

and ^{10}Be+^{64}Zn elastic scattering, a volume potential having a Woods-Saxon (W-S) shape for both the real and imaginary parts was used; the radius and diffuseness (real and imaginary) were fixed and the best χ^2 was obtained by varying the potential depths. Before fixing radius and diffuseness, a series of calculations were performed where they were varied at steps of 0.05 fm.
In the case of the ^{11}Be+^{64}Zn quasielastic angular distribution, the coupling to the break-up was taken into consideration using a Dynamic Polarization Potential (DPP). The DPP used was an imaginary surface potential having the shape of a W-S derivative. No real part for the DPP potential was considered. As volume potential we used the one extracted from the ^{10}Be+^{64}Zn elastic scattering fit. This potential was responsible for the core-target interaction. The OM fit was performed using as free parameter the depth of the DPP potential and varying the diffuseness at steps of 0.05 fm. The best χ^2 were obtained for a DPP diffuseness parameter of $a_{si} \approx 3.5$ fm. A similar diffuseness (a_{si}=3.2 fm) of the surface DPP potential was obtained by [13,14]. The results are shown in Fig. 1. The values of the obtained potential parameters can be found in [7].
As above mentioned, in the ^{11}Be+^{64}Zn case, the inelastic excitation of the bound ^{11}Be state at E_x=0.32 MeV could not be separated from the elastic peak and therefore the quasielastic scattering angular distribution was obtained. We have verified, by means of DWBA calculations, that at each angle the inelastic contribution to the quasi elastic scattering angular distribution is small and hence the quasielastic angular distribution can be considered as elastic scattering angular distribution. This can be seen in Fig. 2. Details of the calculations can be found in [7]. The total-reaction cross-sections deduced from OM analysis for ^{9,10,11}Be+^{64}Zn are σ_R=1090 mb, σ_R=1260 mb and σ_R=2730 mb respectively.

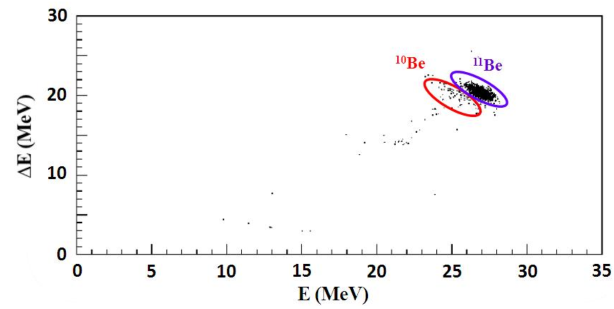

Fig. 3. $\Delta E - E$ scatter plot for the reaction ^{11}Be+^{64}Zn.

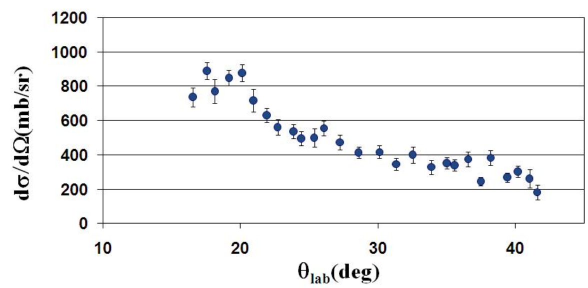

Fig. 4. Angular distribution of transfer/break-up events in ^{11}Be+^{64}Zn obtained by selecting ^{10}Be events in the $\Delta E - E$ spectrum.

3.3 Cross-section for direct reactions

The analysis of the $\Delta E - E$ spectra in the ^{11}Be+^{64}Zn case showed the presence of ^{10}Be events next to the ^{11}Be quasi-elastic peak as can be seen in Fig. 3. Those events could be produced in both 1n transfer or break-up processes. By selecting these events on the $\Delta E - E$ spectra the associated angular distribution was extracted and it is shown in Fig. 4. The integrated cross-section, obtained by assuming that $\frac{d\sigma}{d\theta}$=0 at θ_{lab}=0 and 60° is σ=1100 ± 150 mb, and it corresponds to ≈40% of the exstracted total-reacion cross-section. Therefore, contrary to what found in the weakly bound ^{9}Be case, where at a similar $E_{c.m.}$ energy the total-reaction cross-section is mainly due to fusion [8], in the ^{11}Be case direct processes are giving a large contribution to the extracted total reaction cross-section. These results are in agrement with what previously found in ^{6}He induced collision.

4 Conclusions

In this contribution have been discussed results of elastic and quasielastic scattering angular distribution for the reactions ^{9,10}Be+^{64}Zn and ^{11}Be+^{64}Zn respectively at $E_{c.m.}$≈1.4 the Coulomb barrier energy. In the case of ^{9,10}Be+^{64}Zn similar elastic-scattering angular distributions are observed. These angular distributions show the typical Coulomb-nuclear interference peak. Instead, in the ^{11}Be quasielastic scattering this peak is strongly suppressed, showing that absorption occurs at much longer distances than for the other two non-halo Be isotopes [7]. An OM analysis was performed on the scattering data and the total reaction cross-section was extracted. In the ^{9,10}Be+^{64}Zn a W-S potential was used and only a volume potential was considered. However, in the ^{11}Be case, in order to take the coupling with the break-up into consideration, a surface DPP potential was considered in addition to the volume potential. The DPP used had the shape of a W-S derivative. The volume potential was extracted from the ^{10}Be+^{64}Zn elastic scattering OM fit. The best fit was obtained with the surface term having a very large diffuseness $a_{si} \approx 3.5$ fm in agreement with what found by [13,14]. In the case of ^{11}Be induced collision, a much larger total-reaction cross-section is obtained with respect to the ^{9,10}Be induced reactions. Moreover, in the ^{11}Be+^{64}Zn experiment, transfer and/or break-up events were identified. By measuring the angular distribution for such events it is found that they correspond to about 40% of the total-reaction cross-section.

At the measured energy, above the Coulomb barrier, break-up processes do not play an important role in the weakly-bound ^{9}Be induced collision, where the total-reaction cross-section is found to be similar to the well bound ^{10}Be case.

A behaviour of the elastic angular distribution similar to the one observed in the ^{11}Be case is found in collisions induced by the 2n-halo ^{6}He nucleus on heavy targets where coupling with the Coulomb dipole break-up is important. However, the large suppression of the elastic cross-section in the Coulomb-nuclear interference region has not been observed in the ^{6}He+^{64}Zn [2]. The larger radial distribution of the ^{11}Be compared to the ^{6}He [14] could be responsible for such a difference.

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